

CLAIMS

What is claimed is:

1. A multi-stage filter comprising an upstream prefilter element and a downstream main filter element, said main filter element having tribologically different fibers providing a triboelectric effect.

2. The multi-stage filter according to claim 1 wherein said main filter element is pleated.

3. The multi-stage filter according to claim 1 wherein:

said main filter element comprises pleated filter media having fibers selected from the group consisting of cellulose fibers and synthetic fibers, said pleated filter media having a plurality of pleats extending between first and second sets of pleat tips, said pleats extending generally parallel to a flow direction of fluid through said filter and spaced from each other along a spacing direction transverse to said flow direction and defining a transverse gap therebetween through which fluid flows, such that fluid flows along said flow direction between pleat tips of said first set and then transversely through said pleats and then along said flow direction between said pleat tips of said second set;

said prefilter element comprises a sheet of filter material having a thickness dimension between oppositely facing first and second sides for filtering particles in fluid flow therethrough along said flow direction perpendicular to said sheet and said first and second sides and parallel to said thickness dimension, said second side being adjacent said main filter element, said sheet being formed by an internal pleated subsheet comprising a plurality of fibers and having a plurality of pleats extending between first and second sets of pleat tips, said pleats of said subsheet extending parallel to said flow direction, said first set of pleat tips of said subsheet providing said first side of said sheet, said second set of pleat tips of said subsheet providing said second side of said sheet, said pleats of said subsheet

engaging each other and packed sufficiently tightly against each other such that fluid flows along said flow direction through said pleats of said subsheet in parallel with said pleats, rather than between said pleats of said subsheet and then transversely therethrough, said subsheet having a pre-pleated planar condition with said fibers
25 extending dominantly parallel thereto and dominantly unidirectionally parallel to each other, said subsheet having a pleated condition forming said sheet wherein said fibers extend along said pleats of said subsheet substantially parallel to said flow direction, and said fibers extend around said pleat tips of said subsheet substantially parallel to
30 each respective side of said sheet and substantially perpendicular to said flow direction.

4. The multi-stage filter according to claim 1 wherein said main filter element comprises three sets of fibers, namely a first set having fibers selected from the group consisting of cellulose fibers and synthetic fibers, and second and third sets having said tribologically different fibers.

5. The multi-stage filter according to claim 4 wherein said main filter element comprises two sheets comprising a pleated first sheet having said first set of fibers, and a second sheet having said second and third sets of fibers.

6. The multi-stage filter according to claim 5 wherein said first sheet is between said prefilter element and said second sheet.

7. The multi-stage filter according to claim 2 wherein said main filter element is a planar panel filter element lying in a plane for filtering particles in fluid flowing therethrough transversely to said plane.

8. The multi-stage filter according to claim 2 wherein said main filter element is an annular member having a hollow interior extending along an axis

for filtering particles in fluid flowing therethrough radially relative to said axis.

9. A multi-stage filter comprising an upstream prefilter element and a downstream main filter element, one of said elements including nanofibers.

10. The multi-stage filter according to claim 9 wherein said downstream main filter element is pleated.

11. The multi-stage filter according to claim 9 wherein said downstream main filter element has said nanofibers.

12. The multi-stage filter according to claim 9 wherein said downstream main filter element is pleated and has said nanofibers.

13. The multi-stage filter according to claim 9 wherein said downstream main filter element has said nanofibers, and wherein said nanofibers have: a) a fiber diameter in the range 40 to 800 nm (nanometers); and b) a basis weight in the range 0.02 to 1.0 g/m² (grams per square meter).

14. The multi-stage filter according to claim 9 wherein:

said main filter element comprises pleated filter media having fibers selected from the group consisting of cellulose fibers and synthetic fibers, and having said nanofibers, said nanofibers having a fiber diameter in the range 40 to 800 nm (nanometers) and a basis weight in the range 0.02 to 1.0 g/m² (grams per square meter), said pleated filter media having a plurality of pleats extending between first and second sets of pleat tips, said pleats extending generally parallel to a flow direction of fluid through said filter and spaced from each other along a spacing direction transverse to said flow direction and defining a transverse gap therebetween through which fluid flows, such that fluid flows along said flow direction between

pleat tips of said first set and then transversely through said pleats and then along said flow direction between said pleat tips of said second set;

15 said prefilter element comprises a sheet of filter material having a thickness dimension between oppositely facing first and second sides for filtering particles in fluid flow therethrough along said flow direction perpendicular to said sheet and said first and second sides and parallel to said thickness dimension, said second side being adjacent said main filter element, said sheet being formed by an internal pleated subsheet comprising a plurality of fibers and having a plurality of pleats extending between first and second sets of pleat tips, said pleats of said subsheet extending parallel to said flow direction, said first set of pleat tips of said subsheet providing said first side of said sheet, said second set of pleat tips of said subsheet providing said second side of said sheet, said pleats of said subsheet engaging each other and packed sufficiently tightly against each other such that fluid flows along said flow direction through said pleats of said subsheet in parallel with said pleats, rather than between said pleats of said subsheet and then transversely therethrough, said subsheet having a pre-pleated planar condition with said fibers extending dominantly parallel thereto and dominantly unidirectionally parallel to each other, said subsheet having a pleated condition forming said sheet wherein said fibers extend along said pleats of said subsheet substantially parallel to said flow direction, and said fibers extend around said pleat tips of said subsheet substantially parallel to each respective side of said sheet and substantially perpendicular to said flow direction.

15. The multi-stage filter according to claim 9 wherein said main filter element comprises three sets of fibers, namely a first set comprising said nanofibers, and second and third sets of tribologically different fibers providing a triboelectric effect.

16. The multi-stage filter according to claim 15 wherein said main

filter element comprises two sheets comprising a pleated first sheet having fibers selected from the group consisting of cellulose fibers and synthetic fibers, and having said nanofibers, and a second sheet having said second and third sets of tribologically different fibers.

17. The multi-stage filter according to claim 16 wherein said first sheet is between said pre-filter element and said second sheet.

18. The multi-stage filter according to claim 16 wherein said first sheet comprises pleated first and second subsheets, said first subsheet having said fibers selected from said group consisting of cellulose fibers and synthetic fibers, said second subsheet having said nanofibers.

19. The multi-stage filter according to claim 9 comprising first and second sets of said nanofibers, said first and second sets having tribologically different nanofibers providing a triboelectric effect.

20. The multi-stage filter according to claim 9 wherein said main filter element comprises four sets of fibers, namely a first set comprising said nanofibers, second and third sets of tribologically different fibers providing a triboelectric effect, and a fourth set of fibers selected from the group consisting of cellulose fibers and synthetic fibers and having a fiber diameter substantially greater than said nanofibers.

21. The multi-stage filter according to claim 12 wherein said main filter element comprises a pleated sheet comprising pleated first and second subsheets, said pleated second subsheet having said nanofibers.

22. The multi-stage filter according to claim 21 wherein said pleated

second subsheet is downstream of said pleated first subsheet.

23. The multi-stage filter according to claim 21 wherein said pleated second subsheet is upstream of said pleated first subsheet.

24. The multi-stage filter according to claim 21 wherein said pleated first subsheet has fibers selected from the group consisting of cellulose fibers and synthetic fibers having a fiber diameter substantially greater than said nanofibers.

25. The multi-stage filter according to claim 12 wherein said main filter element is a planar panel filter element lying in a plane for filtering particles in fluid flowing therethrough transversely to said plane.

26. The multi-stage filter according to claim 12 wherein said main filter element is an annular member having a hollow interior extending along an axis for filtering particles in fluid flowing therethrough radially relative to said axis.

27. A direct flow filter comprising a filter element having nanofibers comprising a pleated filter element pleated along a plurality of bend lines, said bend lines extending axially, said filter element having a plurality of wall segments extending in serpentine manner between said bend lines, said wall segments
5 extending axially between upstream ends and downstream ends, said wall segments defining axial flow channels therebetween, said upstream ends of said wall segments being alternately sealed to each other to define a first set of flow channels having open upstream ends, and a second set of flow channels interdigitated with said first set of flow channels and having closed upstream ends, said downstream ends of said
10 wall segments being alternately sealed to each other such that said first set of flow channels have closed downstream ends, and said second set of flow channels have open downstream ends, such that fluid to be filtered flows substantially directly

axially through said filter element, through said open upstream ends of said first set of flow channels then through said wall segments then through said open downstream
15 ends of said second set of flow channels, said pleated filter element having said nanofibers.

28. The direct flow filter according to claim 27 wherein said filter element comprises a pleated sheet comprising pleated first and second subsheets each pleated along said bend lines, said pleated second subsheet having said nanofibers.

29. The direct flow filter according to claim 27 comprising a prefilter element upstream of said pleated filter element.

30. The direct flow filter according to claim 27 comprising a safety filter element downstream of said pleated filter element.

31. The direct flow filter according to claim 27 comprising in combination a prefilter element upstream of said pleated filter element, and a safety filter element downstream of said pleated filter element.

32. The direct flow filter according to claim 28 wherein said pleated second subsheet comprises a plurality of nanofiber layers having a cumulative basis weight in the range 0.02 to 0.5 g/m² (grams per square meter).

33. The direct flow filter according to claim 32 wherein the number of said nanofiber layers is in the range 4 to 7, the Frazier permeability through said nanofiber layers is greater than or equal to 50 fpm (feet per minute), and the nanofibers in each of said 4 to 7 layers have a fiber diameter in the range 40 to 800
5 nm (nanometers).

34. The direct flow filter according to claim 27 wherein said pleated filter element comprises two sheets comprising a first sheet having said nanofibers and a second sheet having tribologically different fibers providing a triboelectric effect.

35. The direct flow filter according to claim 27 comprising first and second sets of nanofibers, said first and second sets having tribologically different nanofibers providing a triboelectric effect.